

We claim:

1 1. A method for forming a metal pattern in a substrate, the
2 method comprising the steps of:

3 depositing a lower hardmask layer on the substrate, the
4 lower hardmask layer having a dielectric constant less than
5 about 4.5;

6 depositing a middle hardmask layer on the lower hardmask
7 layer;

8 depositing a top hardmask layer on the middle hardmask
9 layer, the top hardmask layer having a thickness less than
10 about 200 Å;

11 forming a first opening in the top hardmask layer in
12 accordance with a first pattern, thereby exposing a portion of
13 the middle hardmask layer;

14 forming a second opening in said portion of the middle
15 hardmask layer in accordance with a second pattern and a
16 corresponding opening in the lower hardmask layer, thereby
17 exposing a portion of the substrate;

18 forming an opening in the substrate;

19 depositing metal in the opening in the substrate; and
20 removing the top hardmask layer.

21 2. A method according to claim 1, wherein the top hardmask
22 layer is of a material selected from the group consisting of
23 refractory metals, refractory metal nitrides, refractory metal
24 alloys, doped amorphous silicon and doped silicon.

25 3. A method according to claim 1, wherein the middle hardmask
26 layer is of a material selected from the group consisting of
27 SiO_2 , SiN , SiON and SiOF .

1 4. A method according to claim 1, wherein the lower hardmask
2 layer is of a material selected from the group consisting of
3 SiC:H, SiCOH, SiCNH, carbon-doped oxide, organosilicate glass,
4 silicon oxycarbide, amorphous hydrogenated silicon carbide and
5 amorphous hydrogenated silicon carbide/nitride.

1 5. A method according to claim 1, wherein said step of
2 depositing metal further comprises depositing excess metal
3 overlying the top hardmask layer, and further comprising the
4 step of removing the excess metal by polishing the metal in a
5 chemical-mechanical polishing (CMP) process, a polishing rate
6 of the top hardmask layer being less than a polishing rate of
7 the metal.

1 6. A method according to claim 1, wherein said step of forming
2 the first opening includes depositing a resist layer on the top
3 hardmask layer and subsequently removing the resist layer
4 therefrom, and wherein the middle hardmask layer protects the
5 lower hardmask layer from oxidation during removal of the
6 resist layer.

1 7. A method for forming a metal pattern in a substrate, the
2 substrate having a dielectric constant less than about 4, the
3 method comprising the steps of:

4 depositing a lower hardmask layer on the substrate, the
5 lower hardmask layer having a dielectric constant less than
6 about 4.5;

7 forming a protective layer in a region of the lower
8 hardmask layer adjacent to a top surface thereof;

9 depositing a top hardmask layer on the lower hardmask
10 layer, the top hardmask layer having a thickness less than
11 about 200 Å;

12 forming a first opening in the top hardmask layer in
13 accordance with a first pattern, thereby exposing a portion of
14 the lower hardmask layer;

15 forming a second opening in said portion of the lower
16 hardmask layer in accordance with a second pattern, thereby
17 exposing a portion of the substrate;

18 forming an opening in the substrate;

19 depositing metal in the opening in the substrate; and
20 removing the top hardmask layer.

1 8. A method according to claim 7, wherein the material of said
2 top hardmask layer is selected from the group consisting of
3 refractory metals, refractory metal nitrides, refractory metal
4 alloys, doped amorphous silicon and doped silicon.

1 9. A method according to claim 7, wherein the lower hardmask
2 layer is of a material selected from the group consisting of
3 SiC:H, SiCOH, SiCNH, carbon-doped oxide, organosilicate glass,
4 silicon oxycarbide, amorphous hydrogenated silicon carbide and
5 amorphous hydrogenated silicon carbide/nitride.

1 10. A method according to claim 7, wherein said step of
2 depositing metal further comprises depositing excess metal
3 overlying the top hardmask layer, and further comprising the
4 step of removing the excess metal by polishing the metal in a
5 chemical-mechanical polishing (CMP) process, a polishing rate
6 of the top hardmask layer being less than a polishing rate of
7 the metal.

1 11. A method according to claim 7, wherein
2 said step of forming the first opening includes depositing
3 a resist layer on the top hardmask layer and subsequently
4 removing the resist layer therefrom, and

5 said step of forming a protective layer comprises exposing
6 the lower hardmask layer to a plasma, thereby forming a
7 protective nitride layer in said region which protects the
8 lower hardmask layer from oxidation during removal of the
9 resist layer.

1 12. A method according to claim 7, wherein
2 said step of forming the first opening includes depositing
3 a resist layer on the top hardmask layer and subsequently
4 removing the resist layer therefrom, and

5 said step of forming a protective layer comprises exposing
6 the lower hardmask layer to a plasma which densifies the lower
7 hardmask layer in said region, so that the protective layer
8 protects the lower hardmask layer from oxidation during removal
9 of the resist layer.

1 13. A method according to claim 7, wherein
2 the lower hardmask layer is deposited under conditions
3 such that the material of the lower hardmask layer has
4 increased density in said region adjacent to the top surface of
5 the lower hardmask layer.

1 14. A method according to claim 7, wherein
2 said step of forming the first opening includes depositing
3 a resist layer on the top hardmask layer and subsequently
4 removing the resist layer therefrom, and

5 the resist layer is removed in a non-oxidizing resist
6 strip process.

1 15. A method according to claim 7, wherein the protective
2 layer has a thickness of approximately 100 Å.

1 16. A method for forming a metal pattern in a substrate, the
2 substrate having a dielectric constant less than about 4, the
3 method comprising the steps of:

4 depositing a lower hardmask layer on the substrate, the
5 lower hardmask layer having a dielectric constant less than
6 about 4.5;

7 depositing a top hardmask layer on the lower layer, the
8 top hardmask layer having a thickness less than about 200 Å;

9 forming a first opening in the top hardmask layer in
10 accordance with a first pattern, thereby exposing a portion of
11 the lower hardmask layer;

12 forming a second opening in said portion of the lower
13 hardmask layer in accordance with a second pattern, thereby
14 exposing a portion of the substrate;

15 forming an opening in the substrate;

16 depositing metal in the opening in the substrate; and
17 removing the top hardmask layer,

18 wherein said step of forming the first opening further
19 comprises depositing a resist layer on the top hardmask layer
20 and subsequently removing the resist layer therefrom, and

21 the resist layer is removed in a non-oxidizing resist
22 strip process.

1 17. A method according to claim 16, wherein the material of
2 said top hardmask layer is selected from the group consisting
3 of refractory metals, refractory metal nitrides, refractory
4 metal alloys, doped amorphous silicon and doped silicon.

1 18. A method according to claim 16, wherein the lower hardmask
2 layer is of a material selected from the group consisting of
3 SiC:H, SiCOH, SiCNH, carbon-doped oxide, organosilicate glass,
4 silicon oxycarbide, amorphous hydrogenated silicon carbide and
5 amorphous hydrogenated silicon carbide/nitride.

1 19. A method according to claim 16, wherein said step of
2 depositing metal further comprises depositing excess metal
3 overlying the top hardmask layer, and further comprising the
4 step of removing the excess metal by polishing the metal in a
5 chemical-mechanical polishing (CMP) process, a polishing rate
6 of the top hardmask layer being less than a polishing rate of
7 the metal.

1 20. A method according to claim 16, wherein the resist strip
2 process is a plasma process with a reducing chemistry.

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